3 THE FUTURE POTENTIALS OF NAVIGATION SATELLITES 6

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ABSTRACT

The Navigation Satellite of the 1970-1980 time period can be expected to be an entirely different spacecraft than the presently operational Navigation Satellites of the U.S. Navy. The present day Navigation Satellite is capable of providing only one function-position determination services for ships. The Navigation Satellite of the future will provide a number of services for ships, aircraft (including the supersonic transport) and other advanced types of inter-continental transportation vehicles, such as ground effect machines and hydrofoil boats. These services will be: craft-to-craft communications, passenger telephone service to shore from commercial ships and aircraft, voice and data transmissions between ship and aircraft company business offices and their craft anywhere in the world, high position accuracy to permit reductions in the aircraft separation standards and reduce mid air and ocean collisions, a reliable solar radiation warning for SST type aircraft, up to date weather and sea state reports to ships and aircraft for improved comfort of travel, and en route monitoring of specific aircraft subsystems (engine performance, wing stress, etc.) for relay to a ground station to detect malfunctions.

This satellite will be capable of providing other practical services to mankind during the 1970-1980's. It will provide search and rescue agencies with highly accurate locations of ships in distress, ditched aircraft, lifeboats, and exploration parties who may need assistance. It will be capable of providing scientists with information on the migratory behavior of many types of land and sea animals, large fishes, and large birds. Meteorologists and oceanographers will benefit because free drifting balloons and ocean buoys containing scientific instruments can be located and their data returned to land within minutes.

INTRODUCTION

The Navigation Satellite of the 1970-1980 will be different in appearance and in mission objectives from the one presently in operational usage by the United States Navy for military ships. It will also be radically different from the Navigation Satellite envisaged by the lecturer and science fiction writer of the 19th century - Edward E. Hale. Hale in 1873 in a book entitled "The Brick Moon" [1] described a navigation system composed of four 200 foot diameter spherical satellites placed into 4,200 mile, polar orbits. Two of the satellites were to pass over Greenwich, England and two over New Orleans, Louisiana. The principle employed by this system was to have an object in the sky whose orbital path was known. By measuring the altitude of the satellite above the horizon, a navigator could determine his longitude. Latitude would be found by determining the height of the North star above the horizon. Of course the idea of obtaining longitude via this concept was impractical, we now know, because Earth satellite orbits change with time and so they would not pass over the desired cities.

A Navigation Satellite did become a reality when the U.S. Navy successfully placed into an Earth orbit the Transit satellites. The Navy Satellite System [2], as it is now called, has one basic job to do - to provide ships of the fleet with high accuracy position fixes and in such a way that no one else can tell where the ships are located. The job is done superbly. Position accuracies of 0.1 nautical mile have been quoted. To achieve such precision, large computers are employed, a ship inertial system supplying velocity information is required, and 6-8 minutes of satellite doppler data are obtained and integrated by the computer.

The Navigation Satellite, as used in this paper, will denote a spacecraft whose mission is to provide "useful" services during movements of manned or unmanned terrestrial based vehicles or objects from one point to another. These services are those that will make the travel more economical, safer, and with increased comfort. To meet these objectives the satellite will contain a position determination capability, communications service, weather relay service, and scientific sensors. Before going into the details of the potential services which the satellite may provide to American and world travellers, business men and scientists, a brief introduction of what the future Navigation Satellite might look like is in order.

1/ Number indicates Reference listed at end of paper

SATELLITE DESCRIPTION

The Navigation Satellite of the future will be a large sized spacecraft when compared to our present 140 pound, Scout launched military navigation satellite, shown in Figure 1. The satellite will weigh close to 1000 pounds and be launched by an Atlas Centaur type vehicle. It may turn out not to be one satellite, but two or three totalling to that weight. The determination of the number of satellites is dependent on the particular systems concept selected. A UHF type transponder will be employed to provide the voice and data transmission needs. This frequency will be used because of the increased usage and limited spectrum availability of the presently designated VHF band. UHF will allow wider bandwidths, non-interference with existing VHF ground facilities and high gain satellite antennas. The transponder will be sized to handle the hundreds of aircraft, the thousands of ships and innumerable other users that will be equipped to operate with the satellite. The transponder will be designed to have a multiple access capability. The transponder will employ either frequency or time division multiplexing. This will allow many users to operate through the transponder. To provide the communications and data transfer services a high gain spacecraft antenna will be employed having about 16-20 db gain at UHF. Satellite stabilization will be a three-axis gravity gradient subsystem to be demonstrated on the NASA ATS-D satellite, shown in Figure 2, which is scheduled to fly in 1968, or an active type control subsystem used on the Nimbus 2 satellite , to keep the antenna directed toward the Earth at all times. Solar cells will still be used to provide the 500-700 watts of RF power needed for the electrical system. Chemical batteries will be employed for the peak power needs and during the night or solar eclipse periods. The use of nuclear isotope power may be used if its development has proven to be economical.

ORBITS

When discussing Navigation Satellite Systems one must talk about the most useful orbit for such satellites. There are an infinite variety of orbit possibilities. The Navy's system uses 600 nm circular orbits, inclined 90° to the equator. Non-directive antennas on board the craft must be employed for these satellites. For the services to be outlined later it is desired to have the satellite continuously within view of all, or almost all, potential users of the satellite, and to have relatively simple and low cost user receiving antennas and electronics. This need just about precludes consideration of any but the stationary orbit satellites located 22,300 miles above the equator. Dependent upon the position technique used, 3-6 satellites at the synchronous altitude would provide continuous global services from 70° S to 70° N latitudes. A single satellite navigation system could service the total north and south Atlantic Ocean region. Figure 3 indicates the region of coverage available from one synchronous altitude satellite.

Now that the satellite and its orbit have been outlined, the applications of the satellite will be discussed.

POSITION DETERMINATION SERVICE

The Navigation Satellite will be first of all capable of providing high accuracy position determination services to craft, to people and to shore stations. Aircraft and ships will be provided their latitude and longitude values in terrestrial coordinates with an accuracy of 1 mile or better, dependent on their needs and the amount of money they are prepared to pay for sophisticated equipment. The frequency of the position fix is dependent once again on the needs of the craft. Subsonic aircraft, about once per 5 minutes; supersonic aircraft, once per minute; ground effect machines and hydrofoil boat passenger craft, once per hour; and freighters and conventional passenger liners, once every 3-4 hours. The position information will be provided automatically into the pilot's compartment. The complete position determination sequence is handled automatically via ground station computers. These computers have stored information as to craft code name and frequency of fix. No action need be taken by the craft, unless a more frequent position reading is needed or unless an emergency occurs and the craft's position is needed by shore stations. A review of various Navigation Satellite position determination techniques is contained in reference 3.

What benefits are derived if the above service could be provided?

The Maritime Administration and advanced thinkers in the shipping field have been looking to the day of the automated ship. This is the ship that will leave a port in the United States with a crew consisting of a handful of men, primarily electronics specialists, to operate and maintain the computers and other specialized equipment. The satellite derived position information would be fed directly into the ship's computer to keep the vessel on its pre-set path. The Maritime Administration estimates that celestial position-fixing involves approximately 380 hours annually per ship. On a U.S. flagship it represents about $2,800. They have estimated that the yearly benefit that idealistically could be achieved by 1975 using automatic satellite derived navigation information is between $600,000 and $1,400,00 for all U.S. ships. [4]

The supersonic transport and the subsonic jumbo jets will be able to fly at their desired altitude for maximum engine efficiency and fly a near minimum time path to their destination because the separation standards will be reduced due to the utilization of satellite derived position data. These data, derived independently of an on board computer, will provide the accuracy, reliability and confidence to air traffic controllers and pilots to permit reduction of the present widely spaced separation standards of 120 nautical miles laterally, 20 minute flying time longitudinally and 2000 feet vertically. It has been estimated [5] that if the separation standards were changed to 90 nm laterally, 15 minutes longitudinally and 1000 feet vertically that 46.5 million dollars would be saved annually by aircraft operating in the North Atlantic region only.

COMMUNICATIONS SERVICE

The communications capability offered by the satellite to pilots and traffic controllers can also be provided to passengers as shown in Figure 4. There should be no technological problems to have telephone service, with the same degree of clarity offered to persons on land, from aircraft or ships located far from shores to land. Business messages can be relayed immediately to the man in transit.

Although the in transit telephone service may be a luxury that only a handful may have use for, en route relay of craft operating performance to a terminal maintenance area or to performance analysis station is under serious consideration. The role of the satellite is required for this work. What is envisioned here is the monitoring of specific aircraft subsystems while in flight, as depicted in Figure 5. These could be the engine: where rpm, thrust, fuel flow and structure data would be relayed; the wings, tail, and fuselage: where vibration, stress, and acceleration levels could be measured; and the pilot himself could be instrumented for heart and blood pressure readings. These data would be obtained periodically during a trip (say once every half hour), and relayed to the performance analysis station via the satellite. This station would house large computers. Into these computers would be stored nominal type performance data of various subsystems. The in-flight data transmitted via the satellite would be compared with the nominal information. Significant deviations from the norm would indicate potential problems. After review by experts, appropriate action would be taken. This might be to reduce speed or altitude, feather an engine, or change the pilot. It might only mean that specific engineers or technicians should be at the terminal to diagnose a potential trouble spot. This potential use of satellite technology to aid in the detection of in-flight malfunctions has application to the prevention of mid air disasters, and to reduce the maintenance down time of many of the aircraft, through rapid analysis of in-flight performance data.

TRAFFIC CONTROL

The combination of position fixing and communication services into one system which can provide world wide, all weather and near instantaneous service can serve mankind in a variety of ways. Of prime import is air traffic control and maritime coordination. If aircraft controllers can be provided with periodic and accurate positions of all the aircraft under their area of control then aircraft can be spaced closer together while in-flight, and the key element of a possible collision avoidance system exists. Collision avoidance by use of a satellite might work as follows:

Every five minutes for subsonic aircraft and one-two minutes for supersonic aircraft the latitude, longitude and altitude would be provided to a central station. The determination of these three values would be via satellite and aircraft generated signals, with computation performed at a ground station. These data are placed into our ground computer and displayed on a board. Each aircraft is scheduled to be in his own predetermined volume of airspace, as arranged from a flight plan. Should two aircraft be found (via the satellite generated position data) to be within the same volume of airspace this would indicate that one of the craft is off track and on a potential collision course. Via the communications channel in the satellite the controller can direct the aircraft back on the correct course.

SST RADIATION WARNING

Concern has been publicly voiced [6] of the potential hazards of ionizing solar radiation to the crew and passengers of the supersonic transport. Result of balloon and research aircraft tests clearly indicate that ionizing radiation is a constituent of the environment to be travelled by the SST. It is known that this radiation level can be multiplied several times soon after a solar storm occurs on the sun and sends streams of high-energy protons into the area. Of particular concern to frequent SST airplane passengers and crew members is the integrated radiation dose they will receive.

The Navigation Satellite suitably equipped with solar cosmic ray detectors may provide a method to warn SSTs of approaching high intensity radiation, as shown in Figure 6. The method may operate in such a manner that an r.f. signal is sent to all aircraft within receiving range of the satellite when the energy of the incoming particles at the satellite's altitude exceeds a certain level. The SST on receiving the warning that the critical solar cosmic ray level has been reached will decend to the 40,000 feet altitude level and avoid the high energy particles, due to the breaking down of these particules by the atmosphere. The journey will be continued at the safe altitude until the air at normal operating heights is down to safe radiation levels.

SEARCH AND RESCUE AIDS

The inadequacies of our present search and rescue systems are highlighted during emergencies or disasters, when ships, aircraft and explorers or exploration parties are in trouble or lost. Too much time is spent, after discovering that an emergency exists in finding the vessel or its survivors and in determining which craft is nearest the disabled craft or party. The agencies responsible for the coordination of search and rescue activities (The U.S. Coast Guard and the Defense Department in the U.S. for ocean disasters) need more accurate and timely information of the whereabouts of the disaster for more efficient utilization of the personnel and craft providing the search and rescue assistance.

A Navigation Satellite system shown in Figure 7, could provide precise position location information of the distressed craft to a central search and rescue station. This station would also have knowledge of where the nearest craft is in the area, for quickest rescue. If, for some reason, a craft or exploration party's position, has not been reported by the satellite the ground rescue station would become aware of a potential problem. The last position of the object would be known, materially reducing the area that would have to be searched in order to determine what happened to halt communications. On the average, two extensive air and sea searches for downed aircraft or overdue ships are made yearly, costing about a half-million dollars each.

WEATHER ROUTING

Intra and intercontinental travellers using aircraft and ships have periodically encountered unpleasantness during the trips due to turbulent regions in the air and on the sea. Many of these storm regions are not observable from Meteorological satellites. They are found only by those entering the region of activity and the passengers suffer temporarily. Of even greater concern is the potential damage to the aircraft or ship structure due to the violence of some storms. Normally the craft must reduce speed in order to alleviate possible damage; thereby increasing travel time and cost.

A use of the Navigation Satellite would be to receive the enroute meteorological and oceanographic data from the craft on a periodic and semi automatic basis, shown in Figure 8. For example, sensors on board the aircraft would transmit significant weather data to the traffic controllers. If these data indicate turbulent regions of air at the latitude, longitude, and altitude of travel, directions to avoid this region can be sent to the other craft which will fly in the region. Regions of favorable air streams and ocean currents found during flights will be used to aid others so as to have the most favorable journey for the travellers and the operating companies.

METEOROLOGY AND OCEANOGRAPHY

The needs for a reliable method of position determination and communications on a large area scale are not limited to ships, aircraft, exploration parties or other manned vehicles. Scientific research utilizing manned or automated platforms, such as balloons and buoys, could also benefit from the Navigation Satellite.

Meteorologist presently have no direct method of determining wind speed and wind direction at various altitude levels. These data, along with the corresponding temperature, pressure and humidity readings, will provide the meteorologists with the amount and type of data necessary to allow accurate forecasts weeks in advance vs the few days now. The

Navigation Satellite can provide the location of balloons designed to fly at constant pressure altitudes. Two position fixes spaced at a known time interval will provide a good indication of the speed and direction of the wind which caused the balloon to travel. Via a digital data communications link the balloon's temperature, pressure and humidity sensors can transmit their readings to the satellite at the time the position readings are taken for relay to the ground stations for processing.

In a similar manner, oceanographers can equip free floating ocean buoys with the needed electronics so that it can be interrogated by the Navigation Satellite and its location determined periodically. These position readings can provide data on ocean current velocity. Sensors in the buoy can provide wave height, water temperature and salinity. The potential of this technique for tsunami warning is apparent. The oceanographic data obtained may provide forecasts of ocean storm regions which can aid in routing our merchant ships to the smoothest and quickest path.

ICEBERG WARNING

At present the U.S. Coast Guard spends large sums of money, time and manpower to identify and plot the movement of icebergs. They utilize aircraft to mark the bergs with chloride-rhodamine dye bombs and then observe their drift rate into the shipping lanes of the North Atlantic. These aircraft, it is reported, fly daily missions of more than 33,000 square miles of the North Atlantic. The Navigation Satellite should be capable of providing the location of these icebergs, and periodically chart their movements automatically and at a cost significantly lower than that being performed at present, as depicted in Figure 9. What is required is the placement of a transponder on the berg in such a place that it is maintained in workable condition for a long period of time. Fortunately large icebergs characteristically melt from the bottom so that the operation may be possible using helicopters.

ANIMAL MIGRATION

A section of our biological scientific community has expressed a need for new methods by which they can study the migratory habits of a variety of marine, land and sea life. Figure 10 indicates these animals. What they need is a technique which can provide them the location of the animal under investigation a sufficient number of times during a day so that they can chart its movements. Many scientists need data for a year in order to obtain seasonal variations; others have data needs for a few weeks. In addition to location the scientists desire to obtain particular physiological data on the animal at the time his position is determined. The function of the Navigation Satellite would be to provide the position of the animals under investigation and receive the digital data from the sensors. Miniaturized electronics and power equipment embedded within the animal or attached around the neck or body are required. We will not be able to assist biologist having interests in all types of migratory animals. The hummingbird expert will have to obtain the location of his bird via other than space technology. But large animals such as the polar bear, brown bear, elephant, whooping crane and turtle may well be able to be outfitted with the appropriate electronics, power supply and antenna to operate with satellites. Use of this concept for tracking may prove the means for detecting large herds of animals, and serve to aid the people who hunt them for food and skins.

CONCLUDING OBSERVATIONS

In this short paper I have attempted to predict the potential practical applications of a satellite system which combines a position fixing capability, a data and voice transfer ability and science equipment. NASA has in its program plans to develop the technological needs in this area. I believe the space technology will be on hand when the decision is made to implement such a satellite system. The use of this technology by those government and civilian organizations who can benefit from it is not yet clear. There are many groups who are followers and not leaders of applying the fruits of research and technology. It would be a national disgrace if a catastrophic accident occurred in the air or on the sea which might have been averted had one taken advantage of our new space technology and know-how.

Of equal importance to the technological innovations which Navigation Satellites may provide to us, is the possibility that this satellite will usher in a true and workable means for international space cooperation in the applications area. The satellite can serve all the nations of the world who have airlines and ships. It can prevent accidents to their craft, and aid in saving lives of all peoples.

The United Nations has realized the potential international benefits of a Navigation Satellite. In October 1965 the UN's Committee on the Peaceful Uses of Outer Space passed a resolution noting that there now exists the possibility of development of new communication techniques for radio navigation and traffic control, both at sea and in the air. The Committee invited its Scientific and Technical Subcommittee to study and submit a report on the possibility of establishing a civil world wide navigation satellite on a non-discriminatory basis. Through the UN the Navigation Satellite may be the bridge to international understanding and identification of mutual interests.

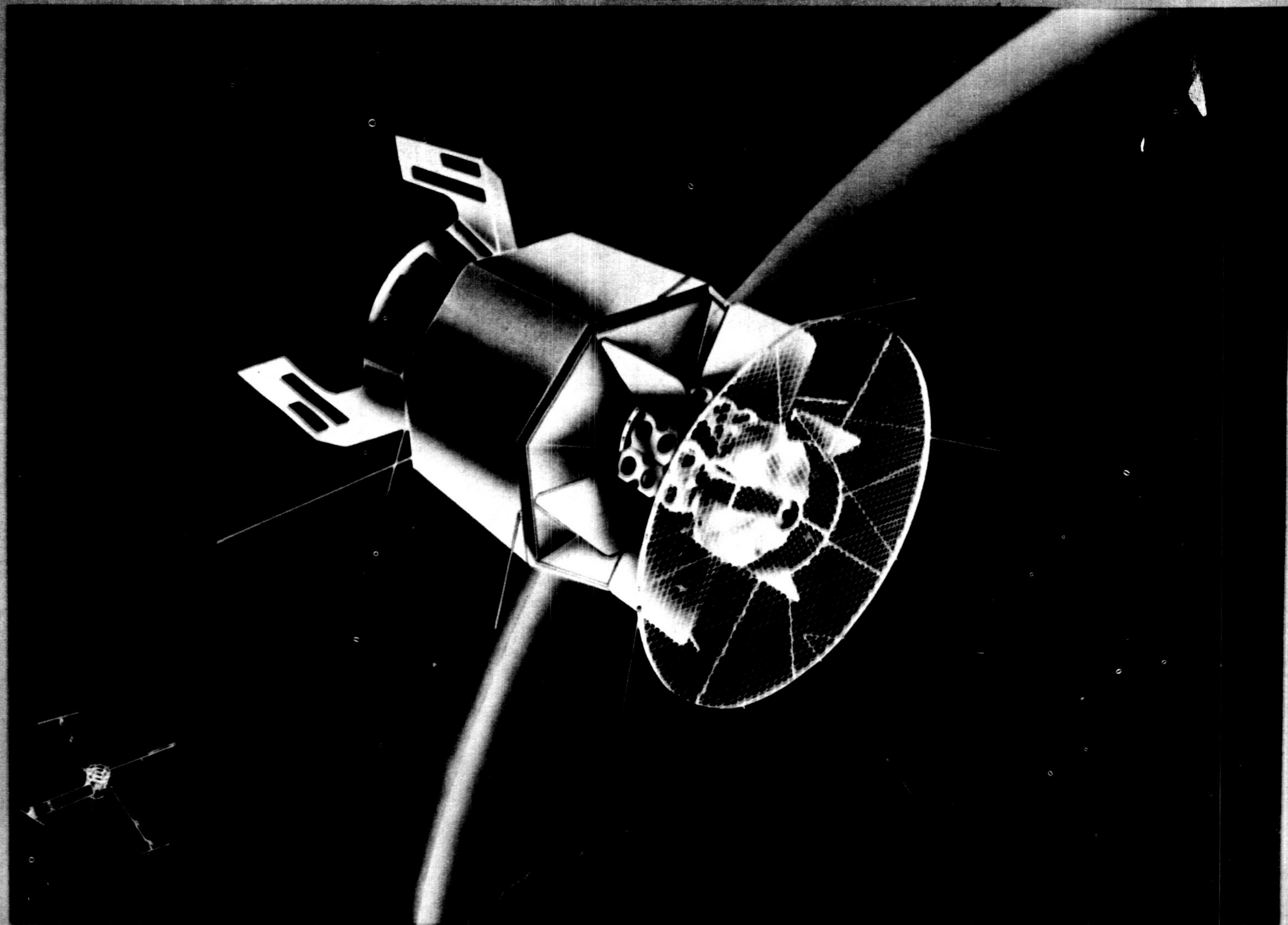
Our technological developments are rapid. The services which I have outlined as "The Future Potentials of Navigation Satellites" are just around the corner. They can be achieved with just a bit more research and development efforts. There are many policy decisions and determinations which must be made prior to the launch of a Navigation Satellite. NASA, I have every hope, will some day demonstrate the capabilities of space technology to achieve what I have described today. It is my fond hope that the civilian user organizations will be as quick to take advantage of the benefits of Navigation Satellites as the military has done. The Navy's Navigation Satellite is successfully guiding our submarines safely around the world. The Navigation Satellite of the future can provide safe travel for our civilian travellers anywhere on our globe.

REFERENCES

1. E.E. Hale, "The Brick Moon, His Level Best, and Other Stories" 1873.
2. R.B. Kershner and R.R. Newton, "The Transit System", Journal of Navigation No. 2, April 1962.
3. E. Ehrlich, "Navigation Satellites for Worldwide Traffic Control", Astronautics and Aeronautics, December 1965.
4. Final Report of the Ad Hoc Joint Navigation Satellite Committee, May 1966.
5. A.H. Skaggs and etc., "The North Atlantic Air-Traffic Control System - Economic Analysis of Proposed Changes" FAA Report No. RD 65-95.
6. S.R. Mohler, "Ionizing Radiation and the SST", Astronautics and Aeronautics, September 1964.

FIGURES

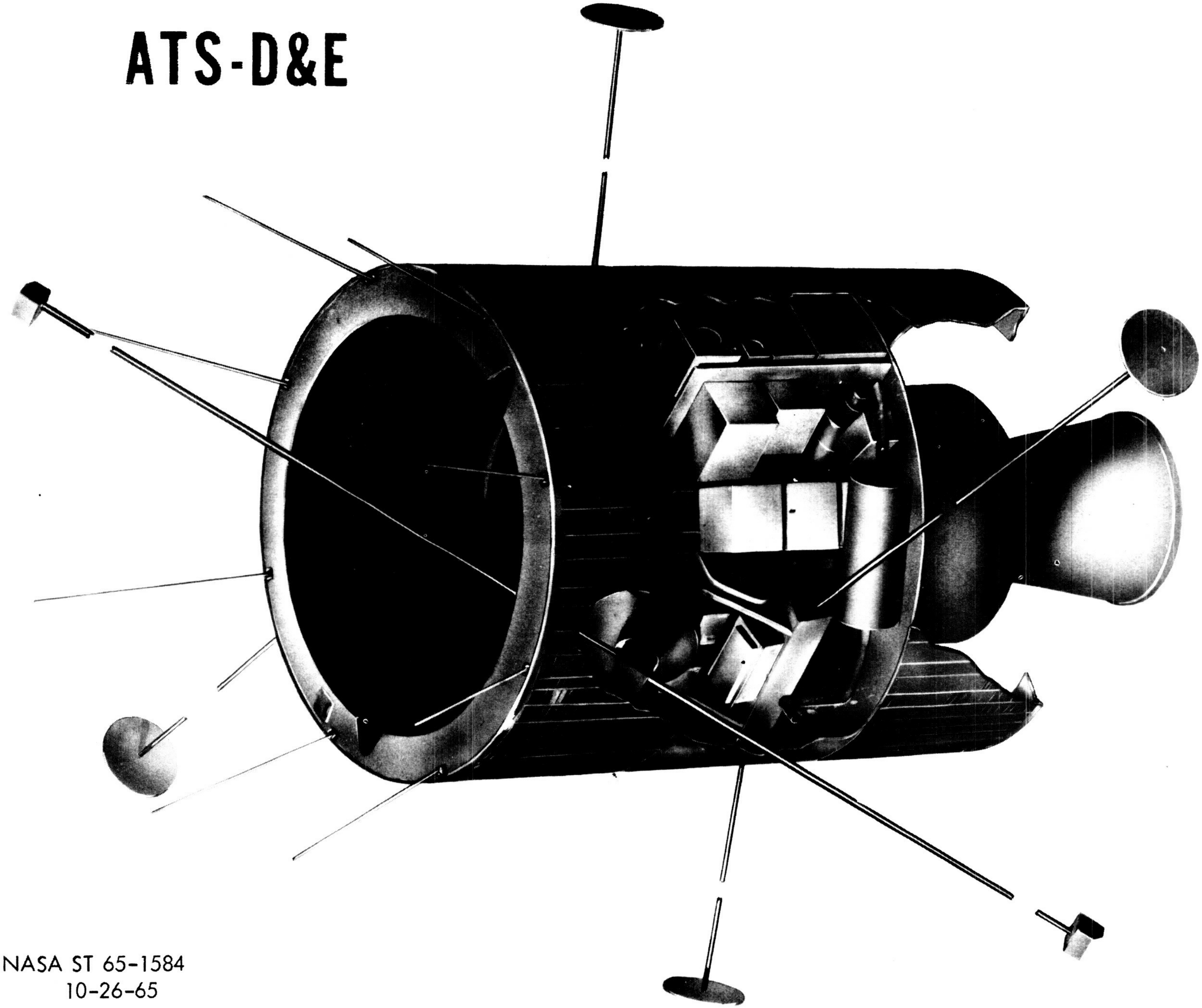
U.S. NAVY NAVIGATION SATELLITES



NASA SP65-15149
2-26-65

FIGURE 1

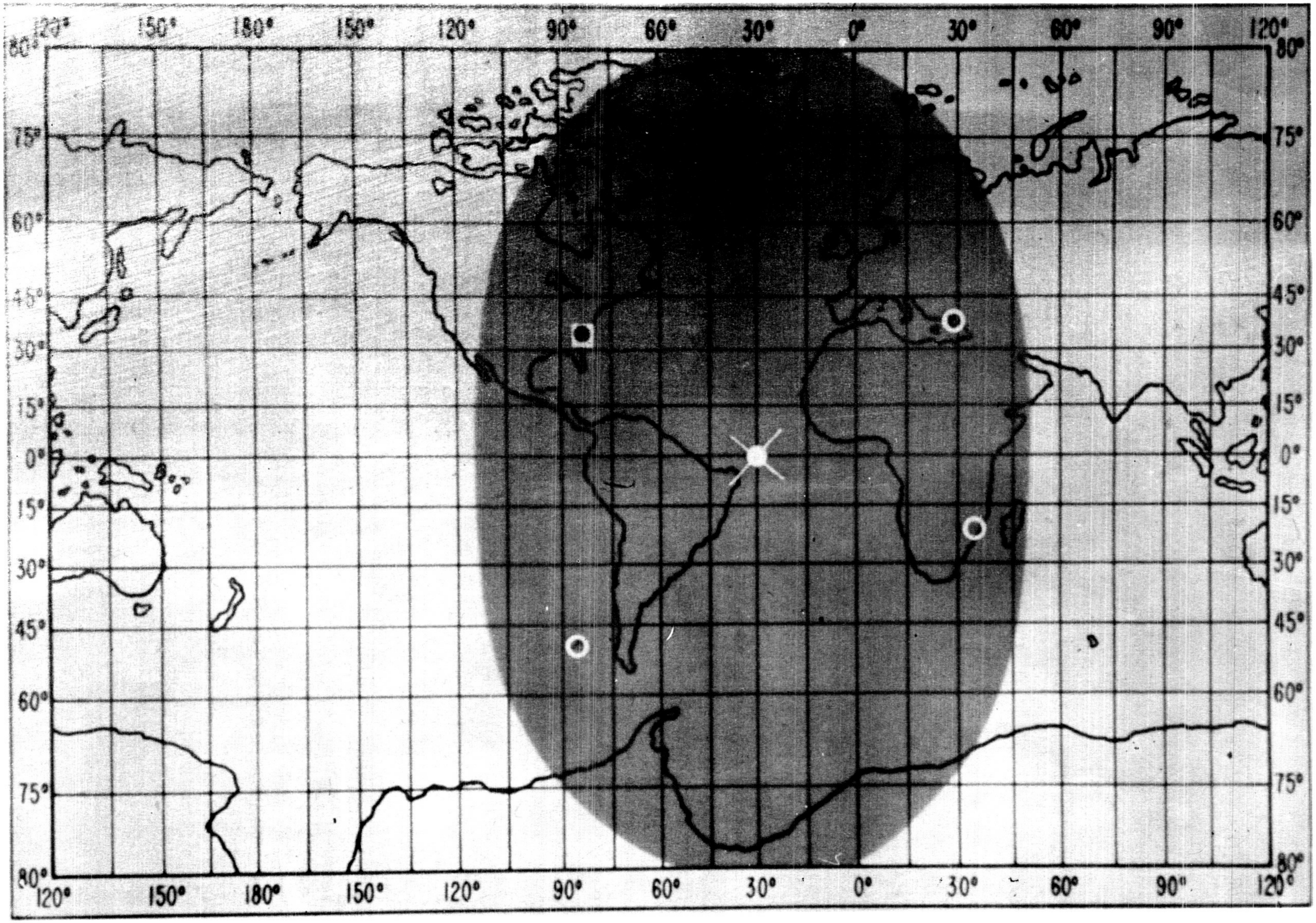
ATS-D&E



NASA ST 65-1584
10-26-65

FIGURE 2

SINGLE GEOSTATIONARY NAVIGATION SATELLITE COVERAGE



SATELLITE   CONTROL / REF STATION   O REF STATION

FIGURE 3


AIRCRAFT TO SHORE PASSENGER TELEPHONE SERVICE
NAVIGATION/TRAFFIC CONTROL SATELLITE
747
NASA HQ SA67-16446
3-28-67

FIGURE 4

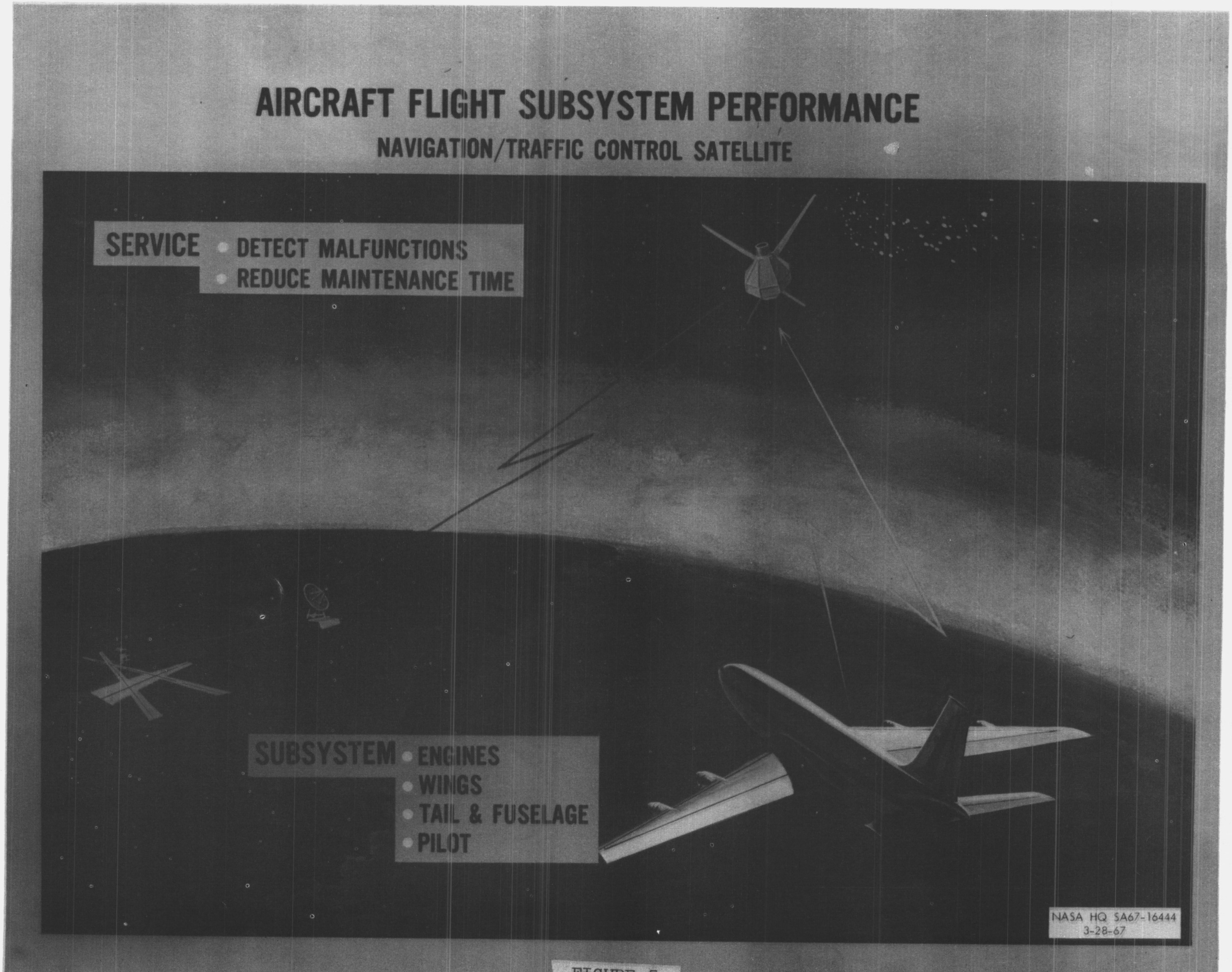

AIRCRAFT FLIGHT SUBSYSTEM PERFORMANCE
NAVIGATION/TRAFFIC CONTROL SATELLITE
SERVICE
DETECT MALFUNCTIONS
REDUCE MAINTENANCE TIME
SUBSYSTEM
ENGINES
WINGS
TAIL & FUSELAGE
PILOT
NASA HQ SA67-16444
3-28-67

FIGURE 5

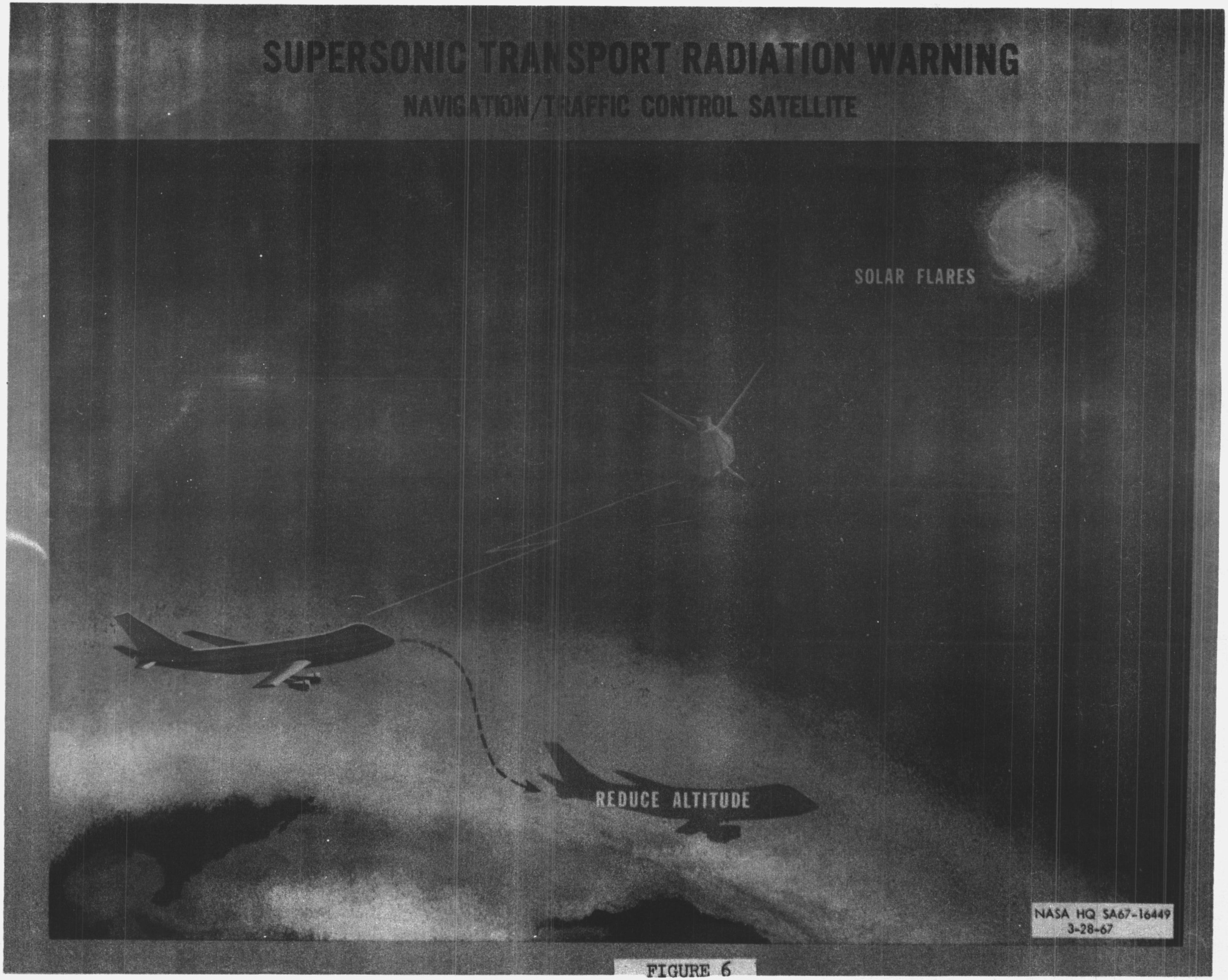

SUPERSONIC TRANSPORT RADIATION WARNING
NAVIGATION/TRAFFIC CONTROL SATELLITE
SOLAR FLARES
REDUCE ALTITUDE
NASA HQ SA67-16449
3-28-67

FIGURE 6

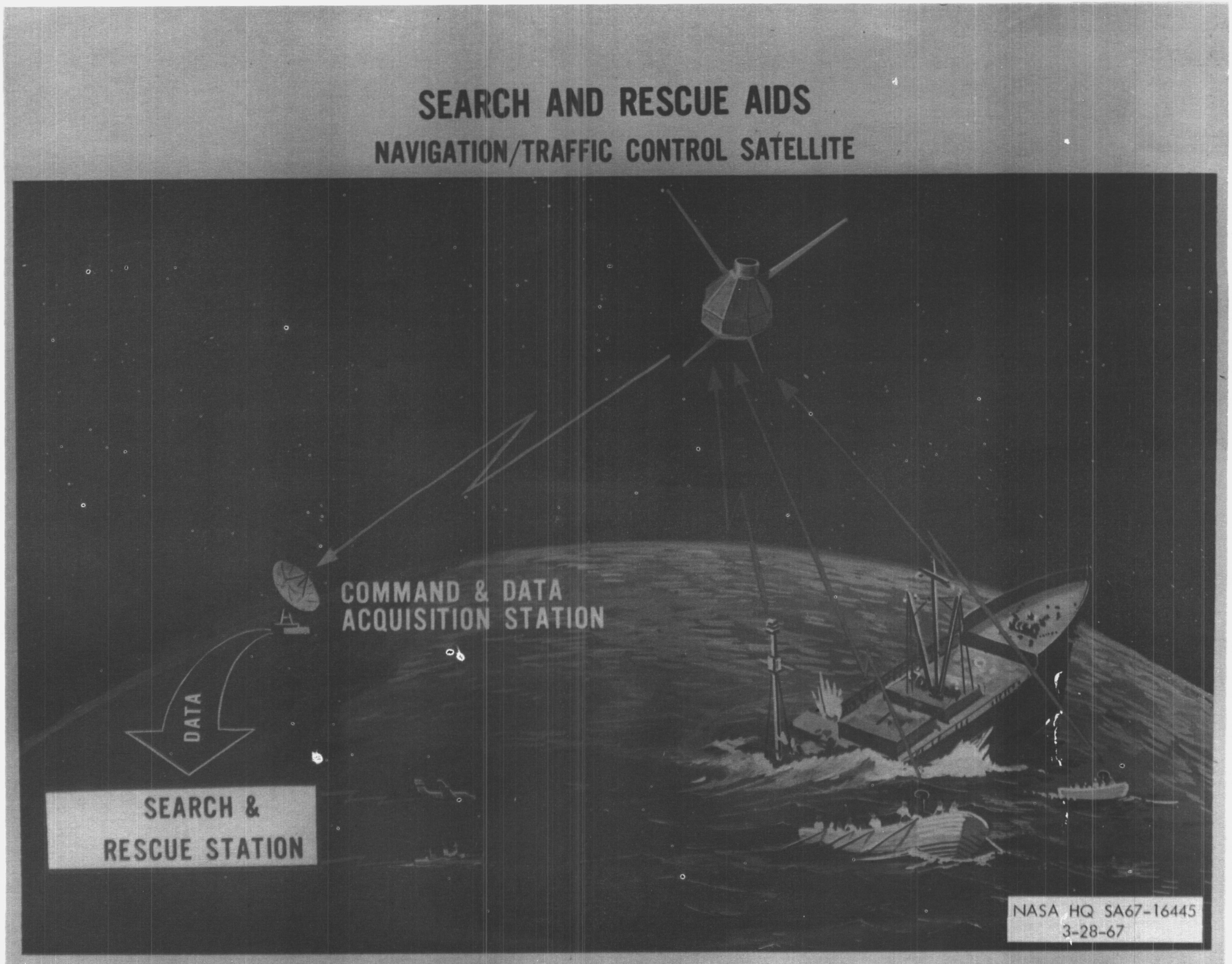

SEARCH AND RESCUE AIDS
NAVIGATION/TRAFFIC CONTROL SATELLITE
COMMAND & DATA
ACQUISITION STATION
DATA
SEARCH &
RESCUE STATION
NASA HQ SA67-16445
3-28-67

FIGURE 7

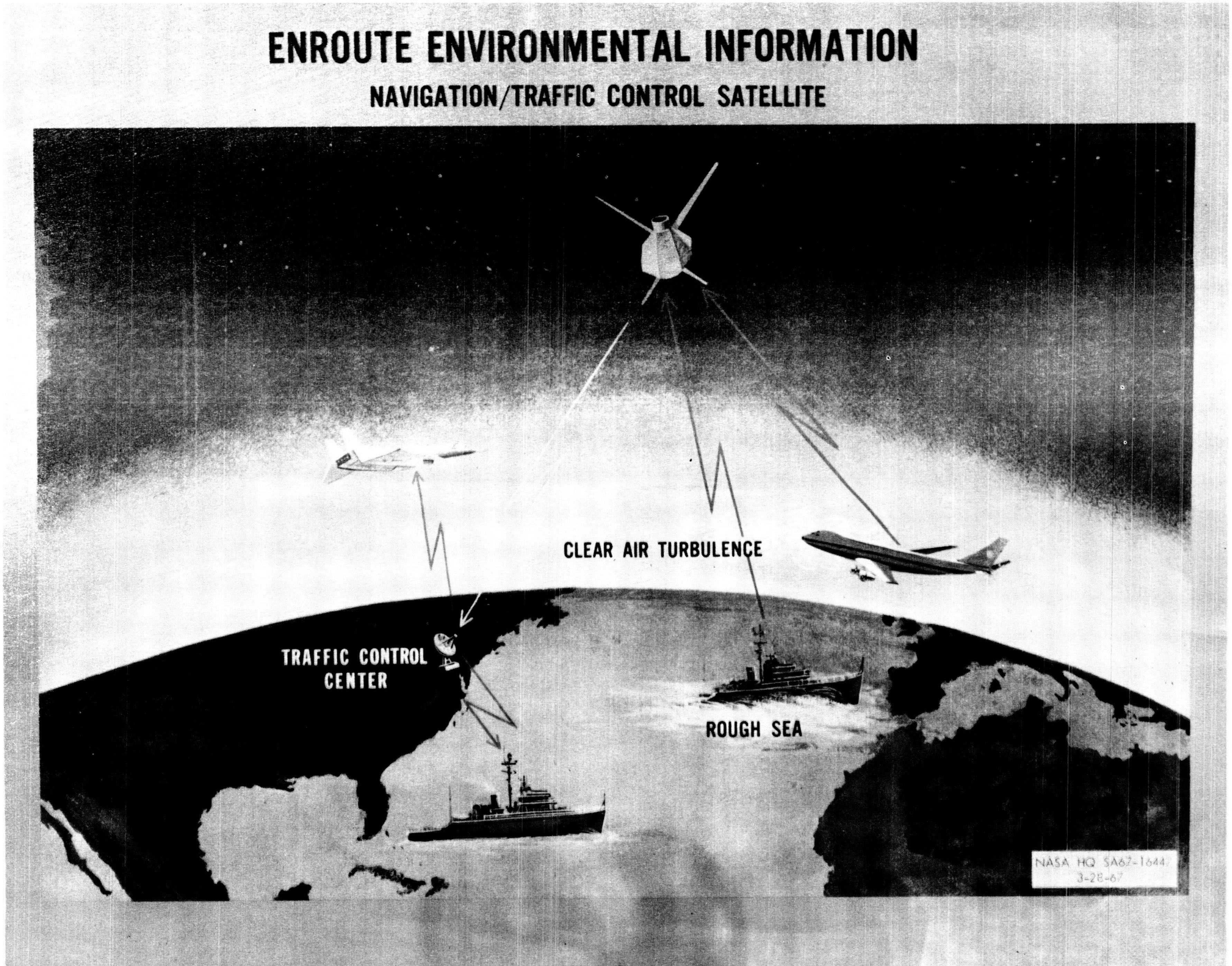

ENROUTE ENVIRONMENTAL INFORMATION
NAVIGATION/TRAFFIC CONTROL SATELLITE
CLEAR AIR TURBULENCE
TRAFFIC CONTROL
CENTER
ROUGH SEA
NASA HQ SA67-1644
3-28-67

FIGURE 8

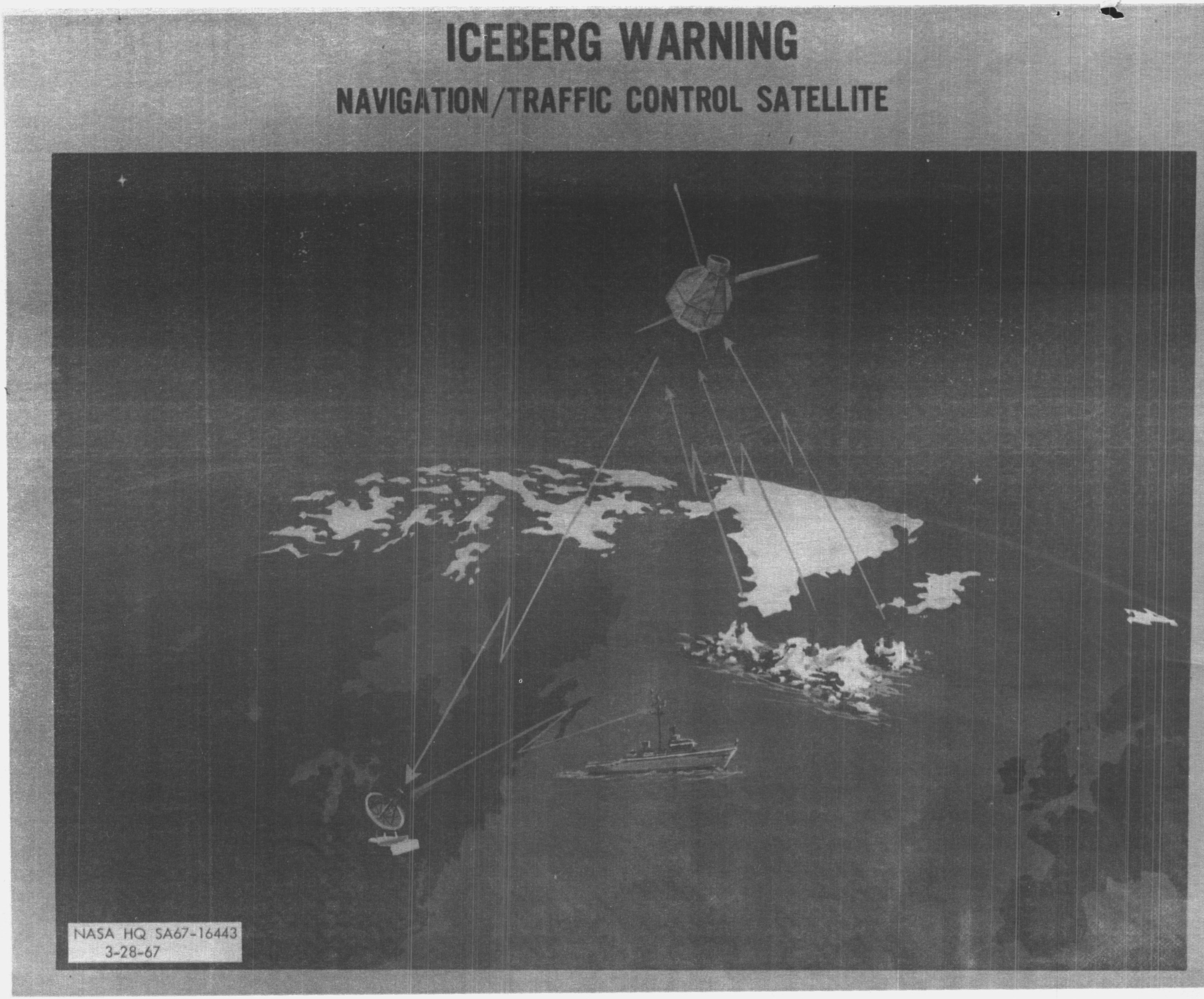

ICEBERG WARNING
NAVIGATION/TRAFFIC CONTROL SATELLITE
NASA HQ SA67-16443
3-28-67

FIGURE 9

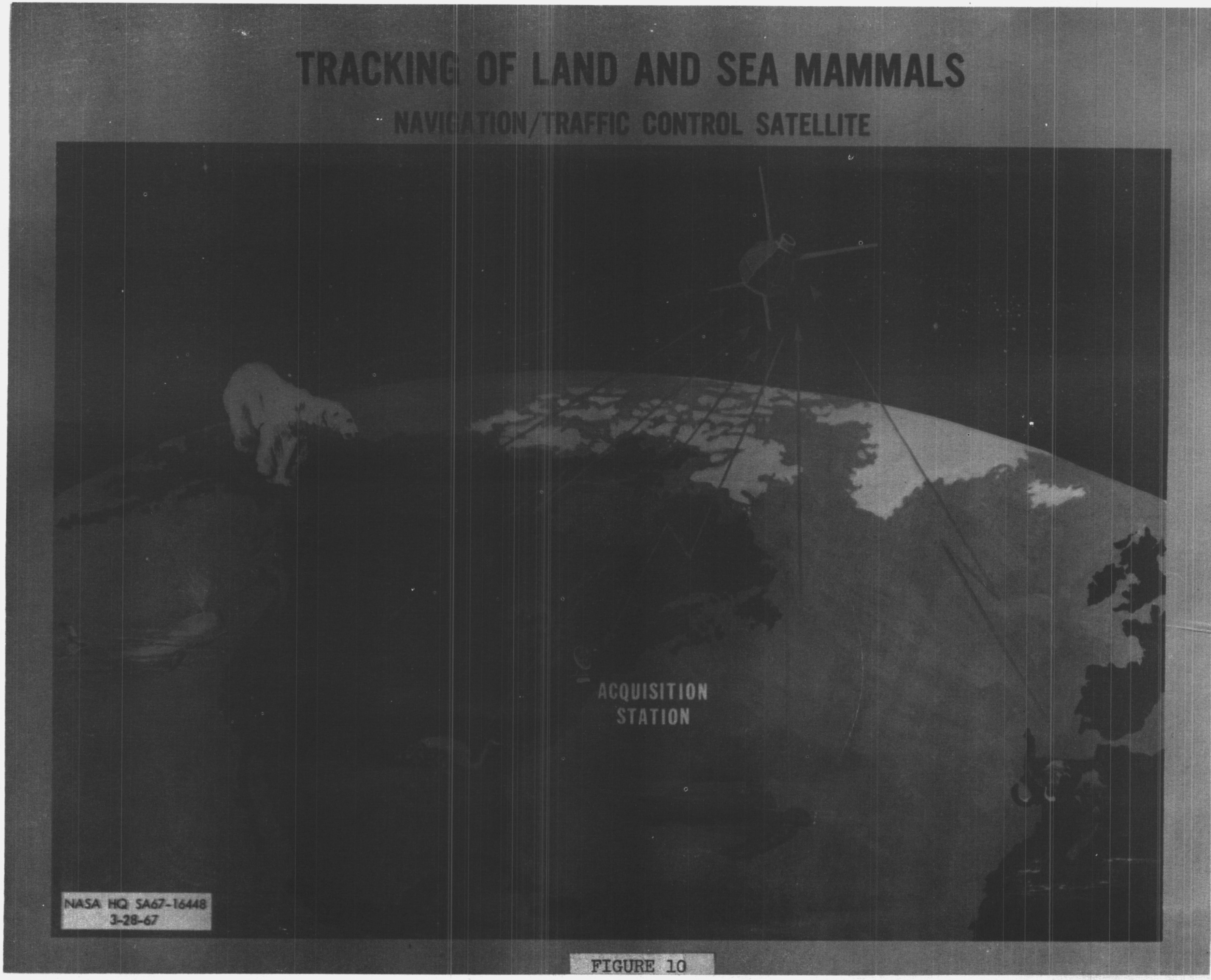

TRACKING OF LAND AND SEA MAMMALS
NAVIGATION/TRAFFIC CONTROL SATELLITE
ACQUISITION
STATION
NASA HQ SA67-16448
3-28-67

FIGURE 10